ASTER
User's Guide

Part III

DEM Product (L4A01)

(Ver.1.1)

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ERSDAC
Earth Remote Sensing Data Analysis Center

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1. Introduction

The Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) is an advanced multispectral imager that was launched on board the Terra spacecraft in December 1999. ASTER covers a wide spectral region with 14 bands from visible to thermal infrared with high spatial, spectral and radiometric resolution. This wide spectral region is covered by three telescopes, three VNIR (Visible and Near Infrared Radiometer) bands with a spatial resolution of 15 m, six SWIR (Short Wave Infrared Radiometer) bands with a spatial resolution of 30 m and five TIR (Thermal Infrared Radiometer) bands with a spatial resolution of 90 m. In addition one more telescope is used to see backward in the near infrared spectral band (band 3B) to give the stereoscopic capability that is the major subject of this User's Guide. The spectral passbands are shown in Table 1-1. The Terra spacecraft is now flying in a circular, near polar orbit at an altitude of 705 km. The orbit is sun-synchronous with equatorial crossing at local time of 10:30 a.m., returning to the same orbit every 16 days. The orbit parameters are the same as for Landsat-7 except for the local time.

The ASTER instrument has two types of Level-1 data: Level-1A and Level-1B data. Level-1A data are formally defined as reconstructed, unprocessed instrument data at full resolution. According to this definition, the ASTER Level-1A data consists of the image data, the radiometric coefficients, the geometric coefficients and other auxiliary data without applying the coefficients to the image data to maintain the original data values. The Level-1B data are generated applying these coefficients for radiometric calibration and geometric resampling. The Level-1A data are used as a source data for generating DEM (Digital Elevation Model) products, since they contain numerous useful instrument geometric parameters as well as the spacecraft information. These parameters can be used to generate high quality DEM data products without GCP correction for individual scenes.

The instrument geometric parameters, such as the line of sight (LOS) vectors and the pointing axis vectors, have been precisely adjusted through validation activity using numerous GCPs. The DEM data, which are processsed only using these system parameters, have been demonstrated to have high degree of accuracy.

Table 1-1 Spectral Passband

Subsystem	Band No.	Spectral Range	Spatial Resolution
VNIR	1 2 3N 3B	0.52 – 0.60 0.63 – 0.69 0.78 – 0.86 0.78 – 0.86	15 m
SWIR	4 5 6 7 8 9	1.600 – 1.700 2.145 – 2.185 2.185 – 2.225 2.235 – 2.285 2.295 – 2.365 2.360 – 2.430	30 m
TIR	10 11 12 13 14	8.125 – 8.475 8.475 – 8.825 8.925 – 9.275 10.25 – 10.95 10.95 – 11.65	90 m

2. Stereo System Configuration

The VNIR subsystem has two telescopes: a nadir-viewing telescope and a backward-viewing telescope, as shown in Figure 2-1. This dual-telescope configuration was adopted to give stereoscopic viewing capability in the along-track direction and to enable a large base-to-height ratio of 0.6 with minimum mass. The single telescope design as adopted for JERS/OPS, can feature only a small base-to-height ratio. The combination of the nadir and backward telescopes is a consequence of the trade-off between performance and resources.

Figure 2-2 shows the stereo configuration. The relationship between base-to-height (B/H) ratio and α is B/H = tan α, where α is the angle between the nadir and the backward direction at a point on the Earth’s surface. The angle α, which corresponds to a B/H ratio of 0.6, is 30.96˚. By taking into account the curvature of the Earth’s surface, the setting angle between the nadir and the backward telescope is designed to be 27.60˚.

A pointing function is provided for global coverage in the cross-track direction, since the swath width of ASTER is 60 km and the distance between neighboring orbits is 172 km at the equator. The optical axes of the nadir and backward telescopes can be tilted simultaneously in the cross-track direction to cover a wider range.

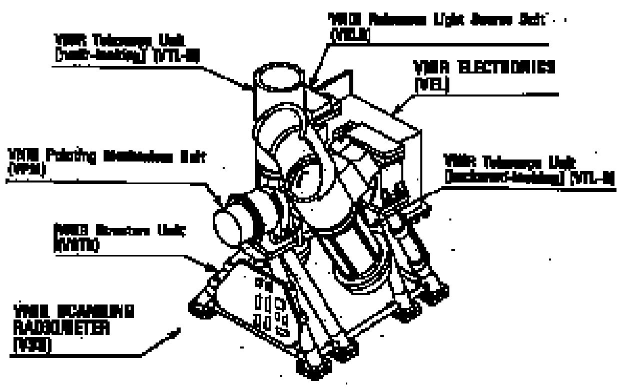

Figure 2-1 VNIR configuration

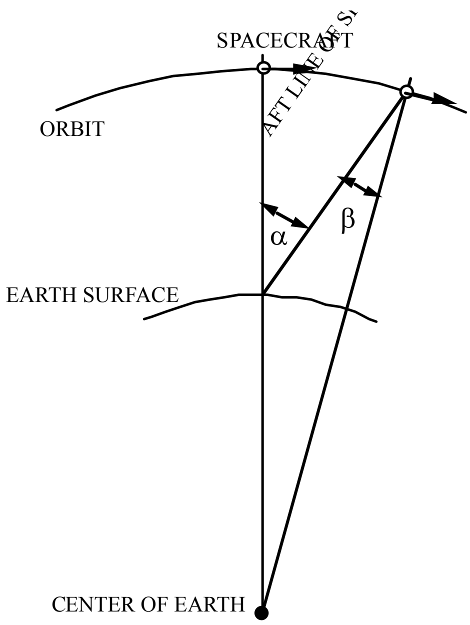

Figure 2-2 Stereo configuration

3. DEM Generation Algorithm

The basic concept of the stereo data algorithm developed is to generate stereo data using the instrument and the spacecraft ephemeris parameters only without referring to the ground control points (GCPs) for individual images.

3.1. Algorithm Flow

Figure 3-1 shows the DEM data generation algorithm flow. It is carried out as follows.

1) to input the Level-1A data.
2) to input the coarse DEM (GTOPO30) database.
3) to apply the radiometric correction coefficients to the image data.
4) to generate the two kinds of scaled-down images for coarse image matching. The reduction rates are 1/2 and 1/4.
5) to evaluate the possibility of the image matching for each correlation window and set the flag. Clouds, bodies of water and incomplete scene edge windows are removed from the image matching object here.
6) to carry out the first stage image matching using the 1/4 compressed image and calculate the parallax.
7) to carry out the second stage image matching using the 1/2 compressed image and the first stage image matching data and calculate the parallax.
8) to carry out the third stage image matching using the full resolution image and the second stage image matching data. The correlation window size is 9 x9 pixels. Prior to the image matching, any image distortion due to terrain error is corrected to improve the correlation.
9) to calculate x, y, and z data for the observation point on the ground every 2 pixels (that is, every 30 m). This process includes the generation of the line of sight (LOS) vectors of detectors for band 3N and 3B expressed by the ECR coordinate frame, and the calculation of the tie point of the extended lines of these two LOS vectors.
10) to output the XYZ data expressed as ECR coordinates.
11) to generate the ellipsoid base (WGS-84) elevation data (height data) using the XYZ data.
12) to resample the height data on a selected map projection.
13) to output the map projected height data (Z data).

The elevation values calculated here are based on the WGS-84 ellipsoid. The formal elevation is not defined as the ellipsoid base but the geoid base. The geoid height correction is necessary for determining the formal elevation values using the geoid database.

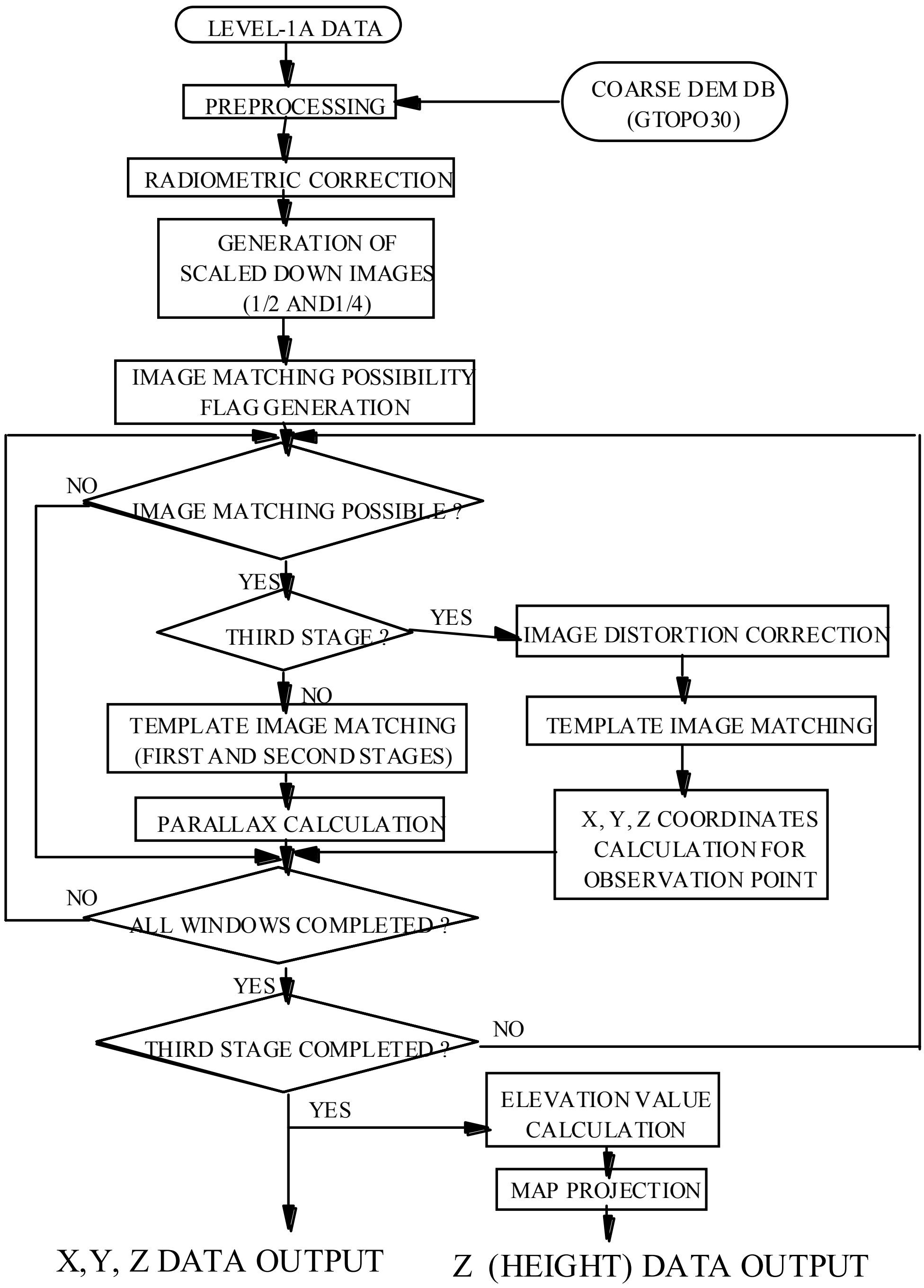

Figure 3-1 DEM generation algorithm flow

3.2. Image Matching Method

To extract the topographic feature from one set of stereo images (a band 3N image and a 3B image), it is first necessary to search for the corresponding point between stereo images. The template matching technique is used to search for the matching points using the correlation coefficient. Template matching involves looking for the closest corresponding point between two images (band 3N and band 3B). As shown in Figure 3-2, the band 3N is the template image with a size of N x N pixels, and the band 3B is the search image with a larger image size than the band 3N. The correlation coefficient is used as an index to find the best corresponding point.

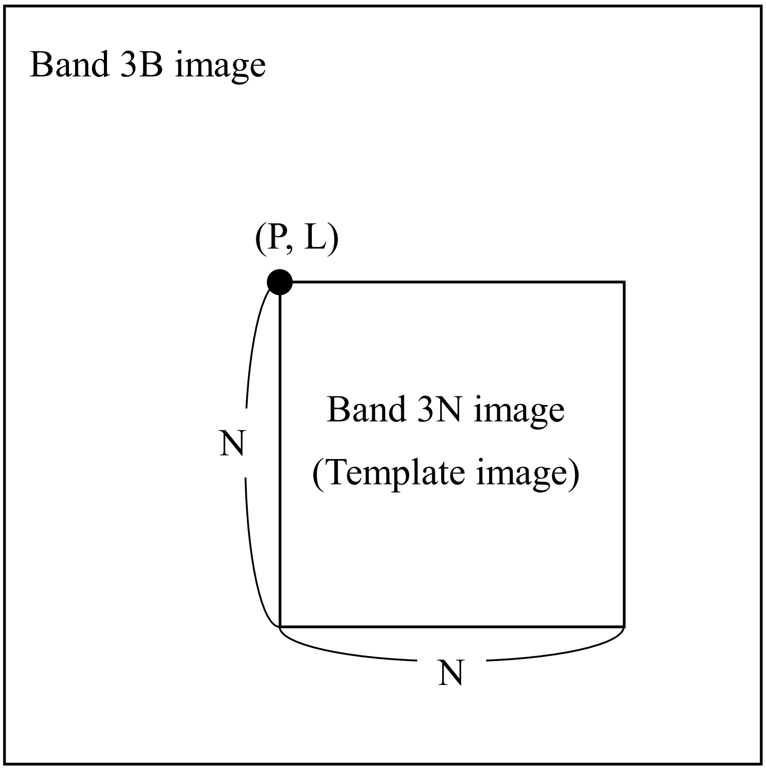

Figure 3-2. Band 3N image and band 3B image in template matching method.

From a set of coordinates for the corresponding point, the spacecraft position and the line of sight (LOS) vectors for the band 3N and the band 3B can be calculated by interpolating the vales at the lattice points which are included in the Level-1A data product. As shown in Figure 3-3, the cross point (P1) of two LOS vectors of the band 3N and the band 3B will be the ground observation point. This method of measuring topographic feature from the intersection point of two LOS vectors is called the bundle method.

Although the nominal parallax (base-to-height ratio) is 0.6, this value is not rigidly fixed: it will depend to some extent on the pixel position and the cross-track pointing angle. Therefore, the bundle method is useful for precisely calculating the ground observation position, including the height data, regardless of the pixel position and the cross-track pointing angle.

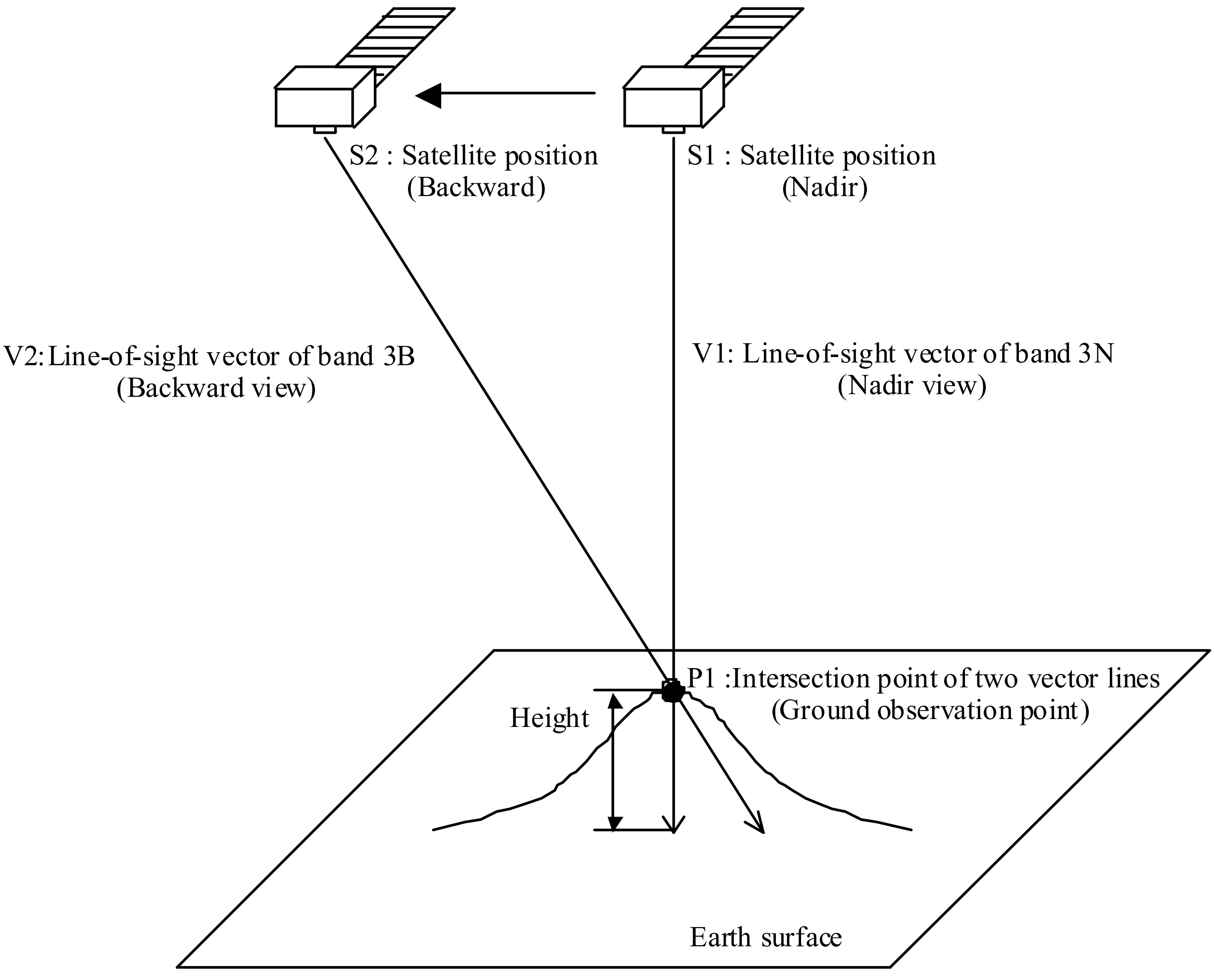

Figure 3-3 Measurement of ground observation point with bundle method

4. Product Description

4.1. Outline of Contents

Currently only DEM Z data products are released to the public.   Figure 4-1 lists these.

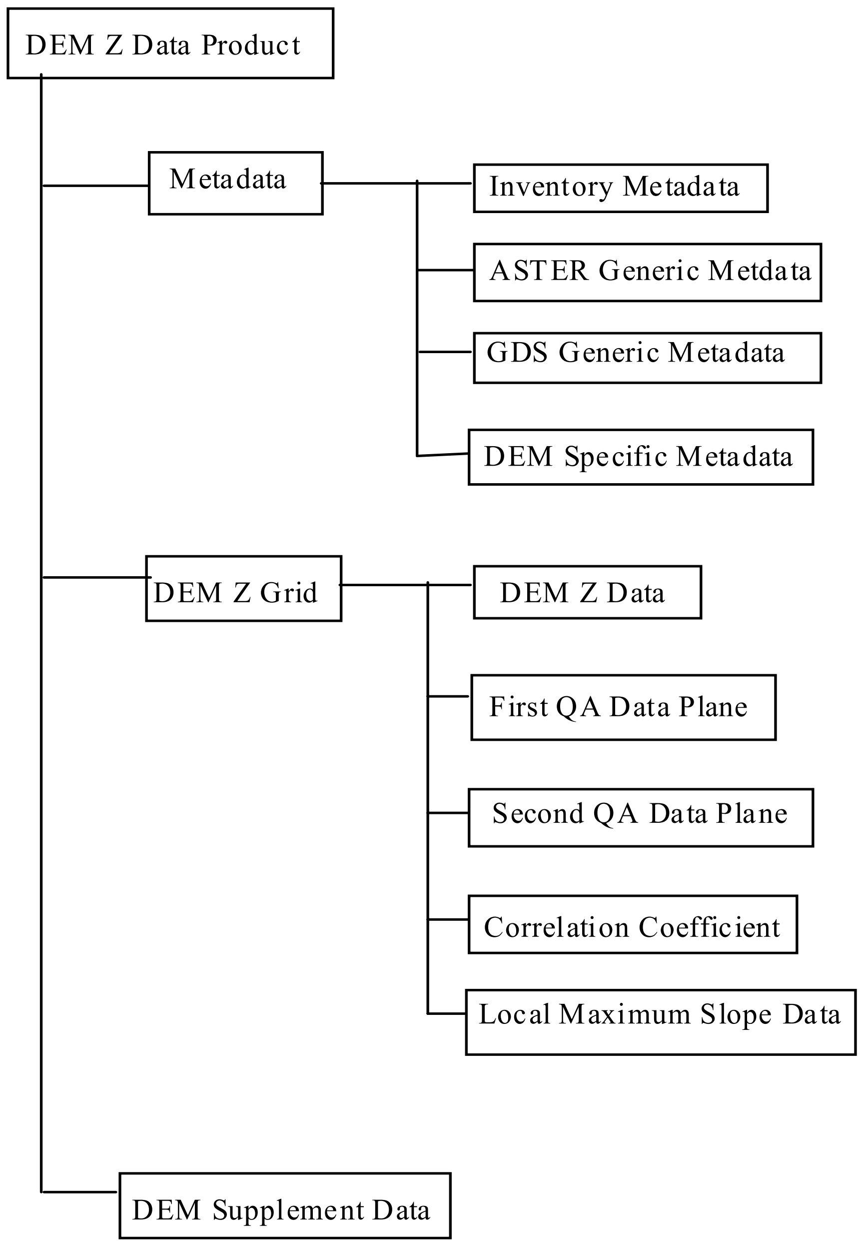

Figure 4-1 DEM-Z data product outline

4.2. DEM Z Data (Elevation Data)

DEM Z data is map projected orthographic elevation data. The following map projections are available .

- Latitude and longitude coordinates (default selection)
- Universal Transverse Mercator
- Polar Stereographic
- Lambert Conformal Conic
- Mercator.

The geodetic map projection is based on WGS-84. Pixel spacing of this data is 30 m (1 arcsecond in the case of latitude and longitude coordinates). The 16 bits are allocated to the elevation data with a resolution of 1 m (1 m/DN). The elevation data is also based on WGS-84 ellipsoid. The formal geoid base elevation can be calculated by subtracting the geoid heights from the WGS-84 ellipsoid base values.

A DN value of –9999 is allocated to bodies of water and other pixel area in which the elevation values can not be accurately measured or interpolated from surrounding data. Interpolated pixels are idendified by flags on the first or second QA plane. Map projection parameters (type of map projection, latitude and longitude of upper left pixel, pixel spacing, etc.) are stored in the supplement data.

Table 4-1 Elevation Data Summary

Item	Description
Data Size	Variable (value in each product is described in DEM Specific Metadata)
Pixel Spacing	30 m (1 arcsec for lat/long coordinates)
Data Type	2-dimensional data array 16 bits integer (signed)
Unit Conversion Factor	1 m/DN
Reference Elevation	WGS-84 ellipsoid
Dummy Area Data	-9999
Abnormal Data	-9999

4.3. First QA Data Plane

The first QA data plane is pixel-level quality assessment information. This plane indicates the status of each pixel: whether it is good, bad, suspect or dummy.

Table 4-2 Format of First QA Plane

Item	Description
Data Size	Variable (same as DEM Z data) (value in each product is described in DEM Specific Metadata)
Data Type	2-dimensional data array 8 bits integer (only lower 4 bits are used)

Table 4-3 Contents of First QA Plane

Category	Binary Code	Description
Bad	0001	Abnormal value pixel of the DEM data.
Suspect	0010	Bad, overflow, underflow, sea or lake pixel of the Level-1A VNIR 3N image, or interpolated DEM pixel.
Dummy	0100	Blank (dummy) pixel
Good	0000	Good pixel

4.4. Second QA Data Plane

The Second QA data are bit flag data which show the state of each DEM pixel data with 8 bit flags: Bad/Suspect, Overflow/Underflow, Sea, Lake/Pond, Cloud, Abnormal value, Blank pixel, and Interpolated pixel. The 5 low-ranking bits show the states of the band 3N image that is used for generation of DEM. The 3 higher-ranking bits show the DEM states

Table 4-4 Format of Second QA Plane

Item	Description
Data Size	Variable (same as DEM Z data) (value in each product is described in DEM Specific Metadata)
Data Type	2-dimensional data array 8 bits integer

Table 4-5. Structure of Second QA Data Plane.

DEM Status			VNIR Status				
8	7	6	5	4	3	2	1

1: Bad / Suspect
2: Overflow / Underflow
3: Sea
4: Lake / Pond
5: Cloud
6: Abnormal Value
7: Blank Pixel
8: Interpolated Pixel

The flags for the sea, lake and pond, and cloud show the result of extracting these areas from the band 3N image using the radiance threshold value. To see the state of the elevation value, it is recommended to refer to the 6th bit flag for abnormal value. Abnormal values result in pixels with low correlation coefficients or area where elevation value changes abruptly. Almost all bodies of water and cloud areas are treated as having abnormal values.

4.5. Correlation Data

The correlation coefficients are the values measured using stereo matching process. The correlation values, which change from 0 to 1.0, are scaled from 0 to 255 using the full dynamic range of eight bits.

Table 4-6 Format of Correlation Coefficient Data

Item	Description
Data Size	Variable (same as DEM Z data) (value in each product is described in DEM Specific Metadata)
Data Type	2-dimensional data array 8 bits integer

4.6. Local Maximum Slope Data

This data provides the maximum slope angle for each pixel. The angle values are ranged from 0 to 90 degrees.

Table 4-7 Format of Local Maximum Slope Data

Item	Description
Data Size	Variable (same as DEM Z data) (value in each product is described in DEM Specific Metadata)
Data Type	2-dimensional data array 8 bits integer

4.7. Metadata

DEM Z Metadata consists of following four groups.

(1) Inventory Metadata
(2) ASTER Generic Metadata
(3) GDS Generic Metadata
(4) DEM Specific Metadata Z

The term "metadata" relates to all information of a descriptive nature that is associated with a product or dataset. This includes information that identifies a paticular dataset, giving characteristics such as its origin, contents, quality, and condition. Metadata can also provide information needed to decode, process and interpret the data, and can include items such as the software that was used to create the data. Metadata entries are described in Object Description Language (ODL) and CLASS system (for two-dimensional arrays). Details are provided in "ASTER Level-4A01 Data Products Specification".

Relation between the metadata and the HDF attribute name is shown in Table 4-8.

Table 4-8 Relationship between Metadata and HDF Attribute Name

Metadata	HDF Attribute Name
Inventory Metadata	coremetadata.0
ASTER Generic Metadata	productmetadata.0
GDS Generic Metadata	productmetadata.1
DEM Specific Metadata Z	productmetadata.z

4.8. Supplement Data

DEM supplement data contains DEM processing parameters.

Table 4-9 Contents and Format of DEM Supplement Data.

Field Name	Order	Variable Type	Description
Ellipsoidal_Parameters	5	DOUBLE	Ellipsoidal parameters (Semi-Major Axis, 1/Flattening, dx, dy, dz)
Map_Projection	8	CHAR	Map projection 'UTM ', 'PS ', 'LATLON ', 'LCC ', 'MERCATOR' (The size of Map_Projection field is fixed (8 bytes). When the length of the data (map projection name) is less than 8 bytes, blanks are added to it.)
UTM_Zone	1	UINT16	UTM zone 1~60
Base_Long	1	DOUBLE	Base longitude line of map projection Longitude: -180.0E~180.0E Use for PS
Base_Lat	2	DOUBLE	Base latitude line of map projection Latitude: -90.0N~90.0N Use for LCC
Interpolation_Mode	4	UINT16	Interpolation mode for Sea pixel, Lake pixel, Cloud pixel and Abnormal value pixel. 0: No interpolation 1: Constant value 2: Interpolation (weighted mean method)
Spatial_Resolution	2	DOUBLE	Spatial resolution X direction and Y direction
Window_size	1	UINT16	Window size of interpolation 1~99
Weight_Coeff	1	DOUBLE	Coefficient of weight for interpolation 1.0~4.0
Start_LonLat	2	DOUBLE	Start east longitude and north latitude
Output_Pixel_Size	2	UINT16	Output pixel size X size, Y size
Supplement_Value	5	INT16	Supplement value for Sea pixel, Lake pixel, Cloud pixel, Abnormal value pixel and blank pixel (sea, lake, cloud, abnormal value, blank)

5. Quality Information

The ASTER DEM products were evaluated comprehensively both for the horizontal values (geolocation value) and the vertical values (elevation). The two methods were adopted to evaluate the accuracy of the DEM products.

1) Comparison of ASTER DEM XYZ data with the high accuracy GCPs.
2) Comparison of ASTER DEM Z data with the more accurate DEM database derived from 1/25,000 topographic maps.

The high accuracy GCPs were prepared in a variety of the validation sites including a mountaineous area with an elevation of about 3000 m. The horizontal and the vertical values for each GCP site are measured using a differential type GPS with high accuracy.

Accuracy of GCPs
Horizontal : better than ±3.5 m
Vertical : better than ±1 m

The same validation sites were observed by different pointing angles to confirm pointing angle dependence.

5.1. Comparison of DEM data with high accuracy GCPs

Table 5-1 shows the results evaluated through the comparison with the high accuracy GCPs. Yatsugatake is an alpine area with an elevation of about 3000 m. The horizontal geolocation accuracy is closely consistent with the reported spacecraft position accuracy of 50 m (3 σ. The elevation accuracy is closely consistent with the accuracy of the instrument system parameters. Roughly speaking, the maximum geolocation error and the maximum elevation error are under 50 m and 15 m, respectively. The maximum error can be roughly estimated as "average + 3 σ".

Table 5-1 Accuracy of DEM data

Site Name	Number of GCPs	Pointing Angle (deg)	Average error (m)			σm		
			Longitude	Latitude	Elevation	Longitude	Latitude	Elevation
Tsukuba	20	0.02	-21.0	5.1	5.1	5.1	6.6	3.5
Yatsugatake	12	8.59	-19.8	12.9	-0.7	12.1	9.0	3.3
Saga 1	7	0.02	-4.3	10.0	-3.2	5.1	5.4	4.8
Saga 2	5	0.02	-13.2	6.8	3.0	8.1	4.6	3.2
Saga 3	11	-5.69	45.8	-3.7	-8.0	6.5	5.1	2.1

A large geolocation errors are due to an imperfect Earth nutation correction in Level-1 processing are reported. See User's Guide 'ASTER Level-1 product' (section for 'Quality Information') for details.

5.2. Comparison of DEM with database

Figures 5-1, 5-2, and 5-3 show the generated three full images of elevation in Japan with one example of the horizontal profile for each image. One example of the elevation error profile for each image is also shown in these Figures.

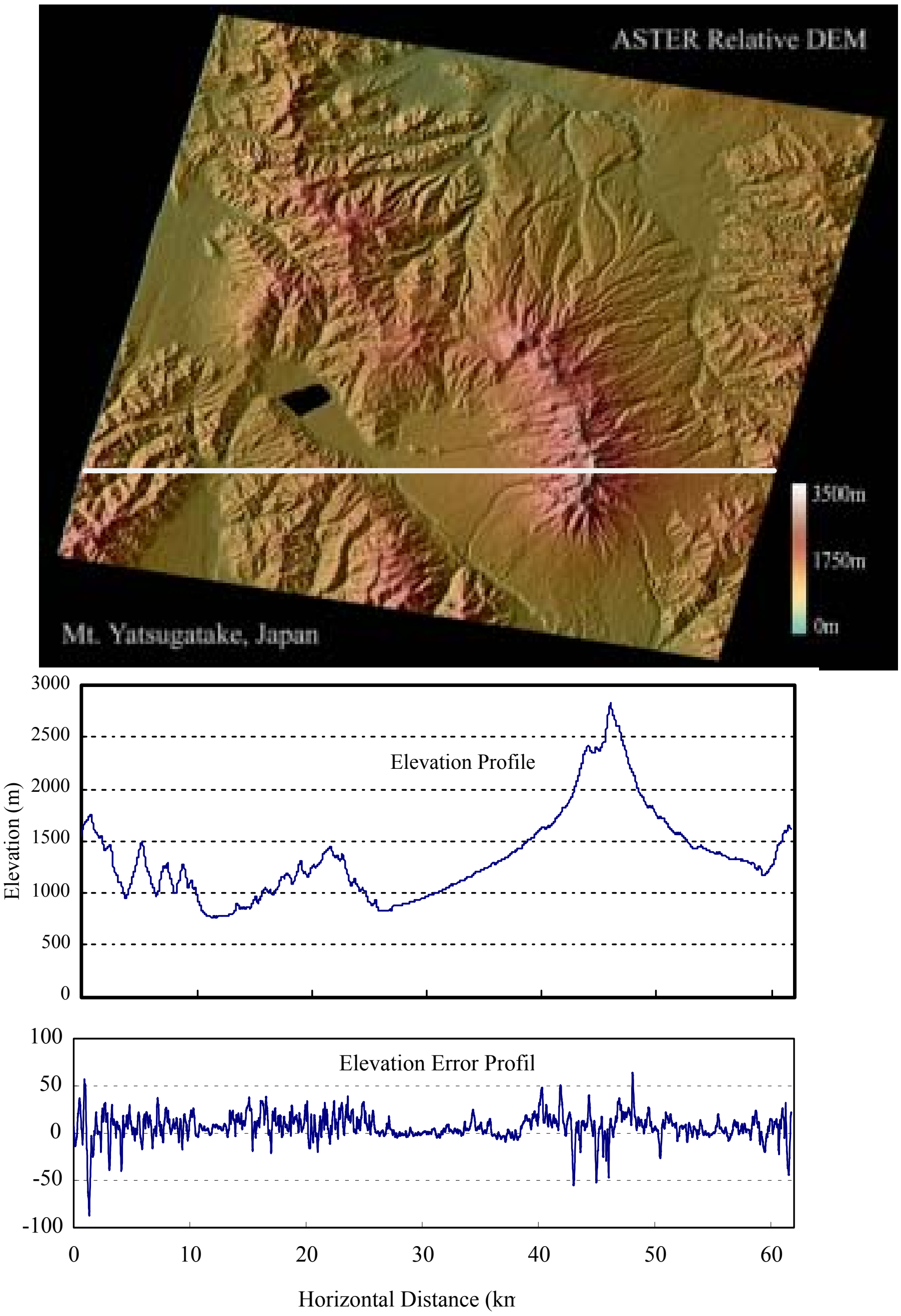

Figure 5-1　DEM data of Mt. Yatsugatake (a typical mountain area in Japan).
The profiles are data along a white line in image.

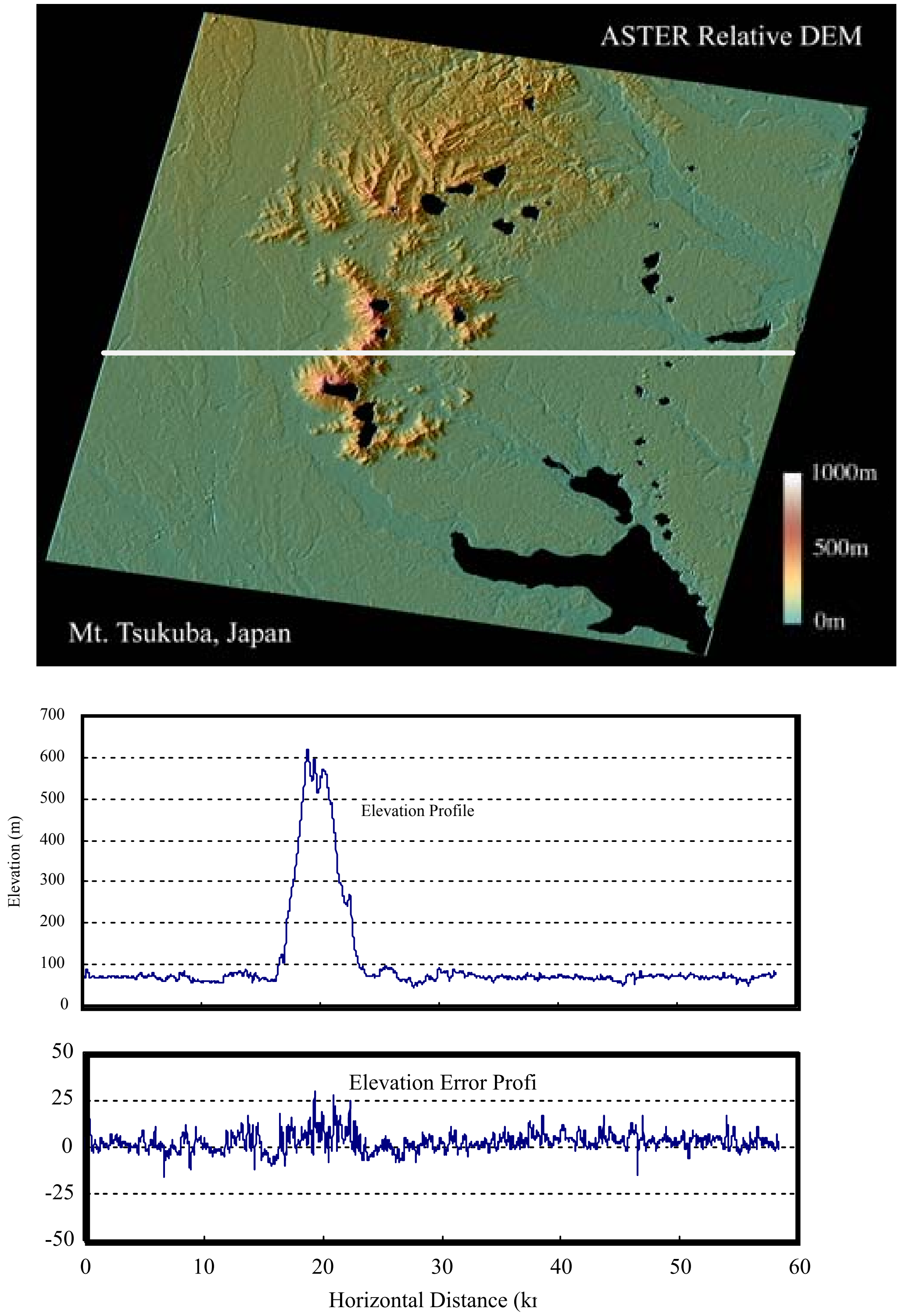

Figure 5-2　DEM data of Tsukuba area.　The profiles are data along white line in image.

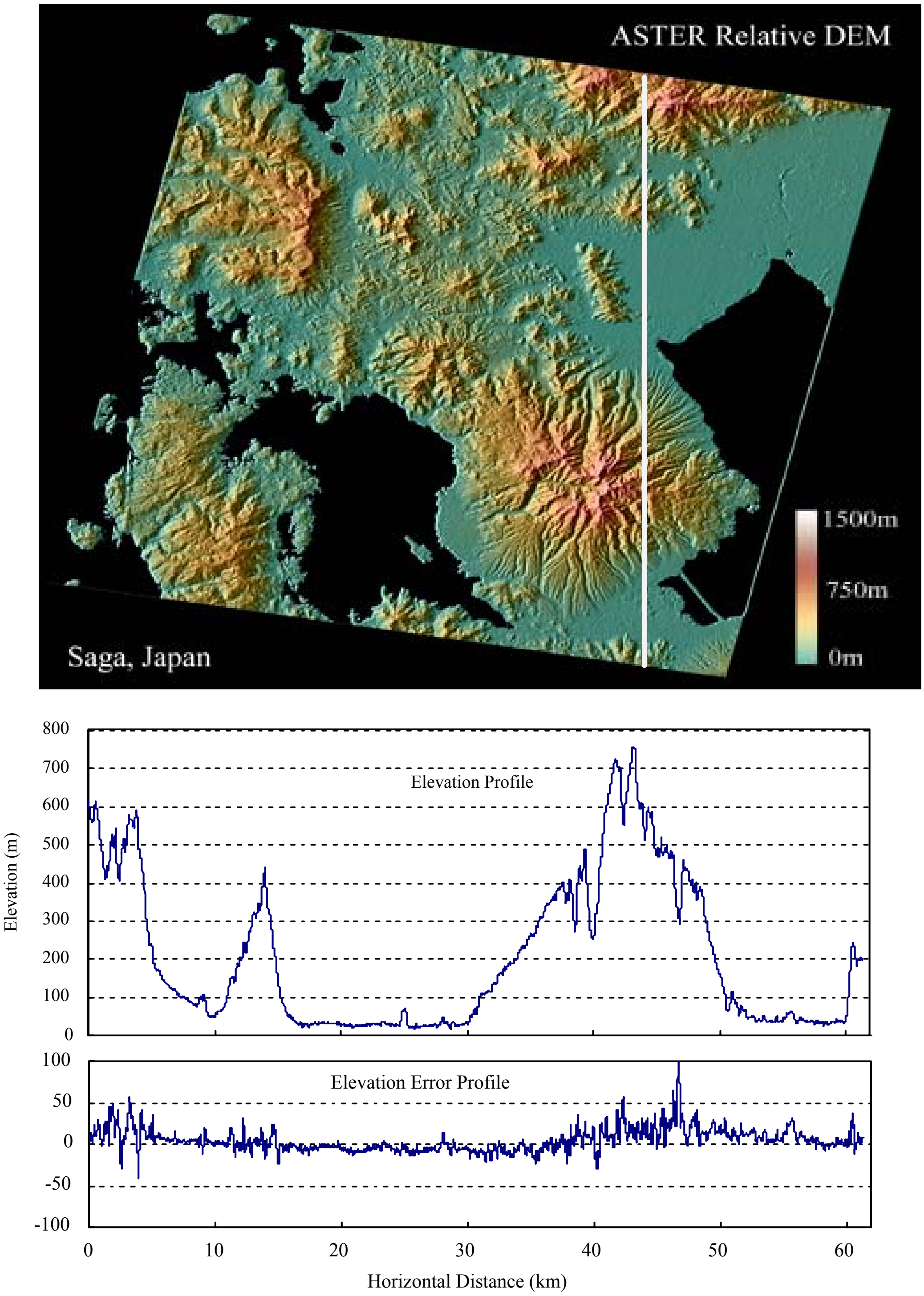

Figure 5-3　DEM data of Saga area.　The profiles are data along white line in image.

The elevation values shown in Figures 5-1, 5-2, and 5-3 are based on the WGS-84 ellipsoid. The geoid heights are 43 m, 40 m, and 32 m for Yatsugatake, Tsukuba, and Saga, respectively. The formal geoid base elevation can be calculated by subtracting these geoid heights from the WGS-84 ellipsoid base values.

The elevation accuracy is closely consistent with the accuracies of the instrument system parameters and the comparison with high accuracy GCPs except for sharp up-and-down sites in mountainous areas.

Figure 5-4 shows two examples of more detailed comparison of measurements with the database in the Mt. Yatsugatake area.

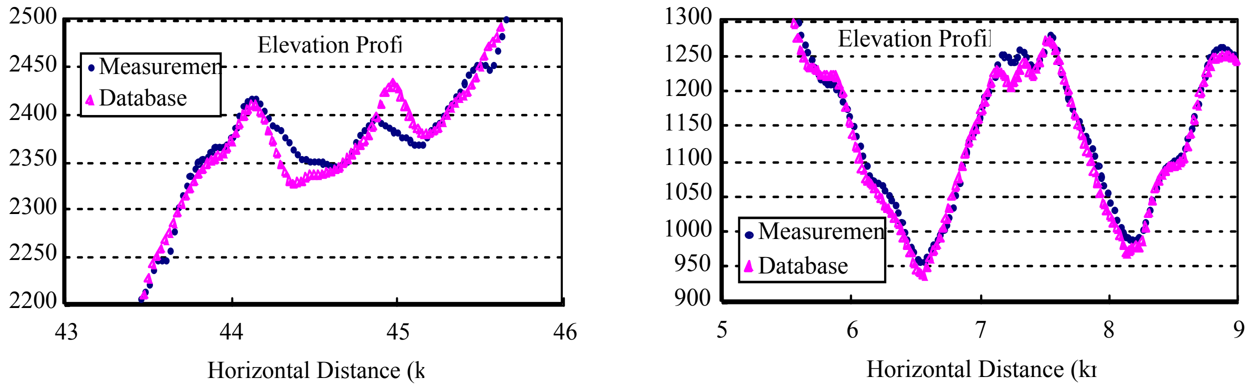

Figure 5-4 Detailed comparison of measurements with database in Mt. Yatsugatege area

5.3. Quality Information Summary

The accuracy of the stereo data generated from the Level-1A data is better than 15 m without GCP correction for individual images. Geolocation accuracy, which is important for the DEM data sets is better than 50 m. This appears to be limited by the spacecraft position accuracy.